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(11) Publication number: **0 454 230 A2**

(12)

EUROPEAN PATENT APPLICATION

(21) Application number: **91200926.3**

(51) Int. Cl.⁵: **G01F 1/86**

(22) Date of filing: **18.04.91**

(30) Priority: **23.04.90 US 513130**

(43) Date of publication of application:
30.10.91 Bulletin 91/44

(84) Designated Contracting States:
DE ES GB IT NL

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(54) **Method and apparatus for determining the mass flow of pneumatically transported solids.**

(57) The suspension density of a pneumatically transported solid, such as coal, is obtained by using a combination of a radial gamma ray densitometer and a second, fast-response density metre. The combination is required to get the desired combination of accuracy and response time. The second measurement is used for its fast response time and may be used to control operating conditions of a gasifier. The slower, but more accurate, radial radiation measurement is used to recalibrate the second measurement approximately every 10 seconds and correct for drift thereof. The drift in the second measurement is sufficiently slow that high accuracy can be maintained by the recalibration technique.

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The invention relates to measuring and controlling mass flow rate in pneumatically transported solids and in particular to the use of one measurement to calibrate a second measurement and thereby achieve a fast and accurate measurement.

Conventional systems for controlling the mass flow rate of fine materials, such as particulate coal, supplied as a fuel into, for example, a furnace such as a coal-fired boiler, generally employ load- cell-based, weight-rate measuring systems to control the gross mass flow rate of the coal to boilers. Such a system is described in U.S. Patent Specification No. 4,490,077. In U.S. Patent Specification No. 4,838,738 the fast response of a mass flow rate-indicating device is combined with the longer term accuracies in changes in the total mass from weigh cells to yield rapid and more accurate loss-in-weight measurements than conventional systems.

U.S. Patent Specification No. 3,635,082 describes the determination of mass flow from velocity and density measurements of a coal and gas stream using two capacitance transducers mounted a known distance apart in the supply line between a coal storage vessel and furnace. The measurement system described by this patent relies on large signal variations, i.e., large changes in flow density, including inducing a change in flow density by injecting a burst of compressed gas into the supply line to produce a marker gap to observe "slugs" of coal in a gas stream in an industrial process. Such a system would not be compatible with a coal gasification process which requires a uniform mass flow rate of coal introduced to the gasifier over periods of time of approximately 5 seconds.

Other conventional systems control the mass flow rate by determining the mass flow rate indirectly via optical measurement of the coal concentration within a conduit leading to the furnace. Accurate control of mass flow by optical measurements, such as radiation absorption of infrared, UV or visible light, is limited to applications of low coal density suspensions, say less than 10 kg/cubic metre, since light must be transmitted through the coal mixture present in the conduit. Knowledge of the particle size distribution is also required. U.S. Patent Specification No. 4,049,394 describes a system for maintaining a predetermined volumetric ratio between fine-particle fuel and a gasification agent which are fed separately into a reactor. This system utilizes the principle of absorption of electromagnetic radiation by the fuel. First, the coal entrains gas as it passes from a storage vessel into a transport line. Additionally, the carrier gas is introduced to assist the coal in discharging from the vessel to the transport line en route to the gasifier. Since it is the total gas stream in the transport line in addition to other factors which govern the mass flow rate, the invention described by this patent could not be used to control the mass flow rate of coal to a gasifier within the desired accuracy, say plus or minus 2 percent, operated with varying suspension densities of 100-800 kg/cubic metre having a variable coal particle size distribution. Typical radiometric density measurements, although accurate, are too slow to ensure constant mass flow rates over short periods of time. U.S. Patent Specification No. 4,270,558, discloses a radiometric density measurement which compensates for the carrier gas. However, such systems do not disclose rapid manual or automatic on-line recalibration of mass flow rate controlling systems within a few seconds to accommodate changing operating conditions as required by the present invention. The present invention is directed to overcoming these problems in the prior art.

It is an object of the present invention to provide an apparatus and a method for determining and controlling, on a fast time scale, the mass flow rate of a solids and gas mixture to a reactor. In particular, it is an object of the invention to provide an apparatus and a method for determining and controlling the mass flow rate of a particulate solid coal and gas mixture to a pressurized gasifier.

The invention therefore provides a system for determining the mass flow rate of a solid transported through a conduit by a gaseous transporting medium characterized by:

- a) a first gamma densitometer for determining the total mass density of said solid and said transporting medium;
- b) a second, faster means for obtaining a direct or indirect measurement of the total mass density of said solid and said transporting medium;
- c) a pressure and temperature sensor for measuring the pressure and temperature of said transporting medium;
- d) means for calculating the density of said transporting medium by using said pressure and temperature measurements;
- e) an integrating computer for calculating the solids density compensated for the density of said transporting medium to obtain a compensated density measurement;
- f) means for periodically calibrating said second densitometer reading with said compensated density measurement to obtain a calibrated density measurement;
- g) means for measuring the velocity of said solids flow; and
- h) computer means for calculating the mass flow rate of said solids from said velocity reading and said

calibrated density measurement.

The invention further provides a method for controlling the mass flow rate to a gasifier of a solid pneumatically transported in a gaseous medium through a conduit to said gasifier characterized by the steps of:

- 5 a) measuring the total gamma density of said solid and said gaseous medium with a first densitometer;
- b) measuring the pressure and temperature of said gaseous medium;
- c) calculating the density of said gaseous medium;
- d) subtracting the gas density from said total gamma density reading to obtain a compensated gamma density reading;
- 10 e) calculating coal volume fraction, f_{coal} ;
- f) measuring coal density, r_{coal} , using a second densitometer;
- g) calibrating said second densitometer by:
 - (1) calculating the average reading of said second densitometer over the last averaging period for said first gamma density measurement and calibrating this reading to equal
 - 15 $f_{\text{coal}}r_{\text{coal}}$; (2) obtaining a corrected mass flow reading by scaling said second densitometer reading with said calibrated reading until said second densitometer reading is updated by the next corrected gamma density reading; and
 - h) controlling the mass flow rate of said solid to said gasifier by adjusting operating conditions of said gasifier with said corrected mass flow reading.

20 The invention combines the use of two separate density measurements to achieve a fast and accurate, gas-compensated coal density measurement in pneumatically transported solids flow. A gamma radiation density measurement may be taken across a diameter of a straight section of vertical pipe. This greatly limits the path length and therefore increases the measurement time required to achieve acceptable accuracy to perhaps 10 seconds. The improvement of the present invention uses a second density
 25 measurement to obtain a fast (but less accurate) response, and recalibrates it once a minute or more often with the slower, but more accurate, radiation measurement. This second measurement is used to control the mass flow rate of the system. The drift in the second measurement is sufficiently slow that high accuracy can be maintained by recalibrating at time intervals compatible with the measurement requirements of the radiation measurement. Thus, in the present invention, mass flow is determined from velocity and density
 30 measurements which are corrected for the density contribution of the transport gas. Velocity is determined from cross correlation of capacitance sensor signals. Density of the transport gas plus the solids is determined by a gamma ray densitometer supplemented with a second density measurement for faster response.

The second density measurement may be any one of the following: A fast but inaccurate radiation
 35 measurement may be obtained by measuring in a large radius curve or a "z" section so that the radiation can pass through a longer path in the transported material. In the present application, a segmented curve is used yielding a response time of approximately one second. In this geometry, the calibration is variable because the particles may redistribute themselves spatially in the curved or "z" section due to variations in velocity or particle size distribution. This results in a fast, but inaccurate, measurement. A fast density
 40 measurement may also be determined from the differential pressure along the pipe. This is obtained, for example, by solving the following equation for the coal suspension density, rc :

$$dp = f[(rg \times vg^2) + (rc \times vc^2)] + (rg \times g) + (rc \times g)$$

45 in vertical flow, or

$$dp = f[(rg \times vg^2) + (rc \times vc^2)]$$

in horizontal flow, where

- 50 dp = differential pressure
- f = friction factor
- rg = gas density
- vg = gas velocity
- rc = coal suspension density
- 55 vc = coal velocity
- g = gravitational acceleration

All of these parameters, except solids density, rc , can be determined by direct measurement or by estimation from averaged data. For this method, the friction factor may vary due to variation in particle size

distribution or physical makeup, so a continual recalibration is required. Measurement of differential pressure and other parameters in this equation requires less than one second. In electrically nonconducting materials, a capacitance density metre may be used for the second measurement. A capacitance density measurement is very fast but is susceptible to variation in suspension dielectric constant and temperature, especially if moisture is present. Coal, for example, will coat the inner lining of the capacitance sensor and, since it has a sufficiently high electrical conductivity, will effectively divert electric field lines around the suspended coal so that the density of flowing coal cannot be sensed.

Advantageously, such an apparatus for the present invention includes:

- (1) a gamma densitometer to accurately measure total mass density of the solids and the transport gas,
- (2) a second density measurement to rapidly measure the density of the solids,
- (3) transport gas pressure and temperature sensors, for obtaining the density of the transport gas,
- (4) an integrating computer to calculate the solids density (compensated for the transport gas) to obtain a corrected density of (1), and
- (5) means for calibrating the second density reading of (2) with the corrected gamma density reading of (4).

The fast, gas-compensated density reading can then be fed to a commercial mass flow metre which will measure velocity by cross correlation and calculate the mass flow required for gasifier control.

Advantageously, a method for controlling the mass flow rate of solids to a reactor according to the invention includes:

- (1) accurately measuring total gamma density and correcting the reading for gas content by calculating gas density from pressure and temperature measurements averaged over the measurement time required for said accurate measurement in order to obtain a corrected gamma density measurement;
- (2) calculating the coal volume fraction;
- (3) obtaining a second density reading;
- (4) calibrating the second density reading by:
 - a. calculating the average reading of the second densitometer over the last averaging period for the gamma densitometer and calibrating this reading to equal $f_{\text{coal}} r_{\text{coal}}$ where F_{coal} = volume fraction of coal in the pipe and r_{coal} = coal density; and
 - b. scaling the second densitometer readings accordingly until they are updated by the next corrected gamma density reading from (1);
- (5) controlling mass flow rate by adjusting operating conditions of the gasifier utilizing the calibrated density reading of step (4).

The invention will now be described by way of example in more detail by reference to the accompanying drawings, in which:

- Fig. 1 illustrates an advantageous embodiment of the invention;
- Fig. 2 is a block diagram of the invention with instrumentation and computer interface;
- Fig. 3 is an enlargement of the instrumentation required for a fast gamma densitometer measurement; and
- Fig. 4 is a schematic diagram of the system instrumentation integrated with a computer.

Generation of synthesis gas (syngas) occurs by partially combusting organic or carbonaceous fuel, such as coal, at relatively high temperatures in the range of 800-2000 °C and at a pressure range of from about 1-200 bar in the presence of oxygen or oxygen-containing gases in a gasifier. Oxygen-containing gases include air, oxygen enriched air, and oxygen optionally diluted with steam, carbon dioxide and/or nitrogen.

In the present invention, the fuel and gas mixture is discharged from a feed vessel apparatus, advantageously having multiple outlets, each outlet being in communication with at least one burner associated with the gasifier. Typically, a gasifier will have four burners in diametrically opposing positions. Generally, the burners have their discharge ends positioned to introduce the resulting flame and the agent of combustion into the gasifier.

Of particular importance in the manufacture of synthesis gas is the uniform manner in which the particulate fuel is introduced to the burners within the gasifier and, in particular, the uniform mass flow rate of the fuel. Fluctuations of coal mass flow rate to burners within a coal gasification reactor, hereinafter referred to as a gasifier, are detrimental to the gasifier's performance. For example, fluctuations of the coal mass flow rate can cause inefficient combustion of fuel within the gasifier, i.e. zones of underheating generated next to zones of overheating in the gasifier. As a result, in the zones of underheating the fuel is not optimally gasified and in zones of overheating the fuel is completely converted into less valuable products, viz. carbon dioxide and water vapour. Additionally, damaging heat fluxes to the burner face can cause thermal stresses possibly resulting in shorter burner life. Furthermore, local high temperatures in the gasifier could damage the refractory lining which is normally arranged at the inner surface of the gasifier

wall.

Based on the reasons identified above, maintaining a uniform mass flow rate of a coal and gas mixture to a gasifier is essential to effectively operating a gasifier. Since the residence time of coal in a gasifier can be 5 seconds or less, the coal mass flow rate should be constant over periods of this order and over longer
5 periods to maintain constant local conditions.

As previously noted, measurement and automatic on-line control and recalibration of coal mass flow rate to the burners of a gasifier by conventional means, such as weigh cells, or a single radiometric density measurement are too slow (or inaccurate) to ensure a constant mass flow rate to the burner of a gasifier over the time periods stated above. Similarly, other systems for controlling the mass flow rate by
10 determining the mass flow rate indirectly via optical measurement of the coal concentration within a conduit leading to the furnace are limited to applications of low coal density suspensions. Furthermore, the present method and apparatus disclosed herein for determining the mass velocity of the coal, allows the flexibility of operating the process at varying, and higher, suspension densities, say 100-800 kg/cubic metre, and at varying moisture contents of coal, which are characteristic of different coal types.

15 In a coal gasification process, coal is transported pneumatically by a suitable gas, for example, nitrogen or synthesis gas, in a small diameter (say 15 mm) pipe. A measurement of coal mass flow is needed to control the operation of the gasifier and is currently determined as follows:

- (1) velocity is determined by cross correlation of signals from two closely spaced velocity sensors;
- (2) flow density (pounds of coal per unit pipe volume) is measured by a single radiation measurement;
- 20 and
- (3) mass flow rate is computed by multiplying the coal flow density times the velocity times the pipe cross sectional area.

This system is not adequate for the above-noted reasons and improvement is required.

A radiation measurement may be obtained by injecting a beam of gamma rays through the pipe and
25 measuring the degree of attenuation of the beam as it emerges from the pipe and impinges on a radiation detector. The more coal in the pipe, the greater the attenuation of the beam. Since this technique is sensitive to all mass present in the pipe, it must be corrected for the transport gas to give a net coal density.

The time required to get an accurate radiation measurement decreases with increasing path length in
30 the mass to be measured. The desired accuracy response is about 0.5% for a one-second measurement. To get a sufficiently long path in the small diameter pipe, two 45-degree transitions may be introduced in the pipe in going from vertical transport (from the ground to the burner level of the gasifier) to horizontal transport into the burner. The transition is actually accomplished through a gradual curve in order to avoid excessive erosion of the pipe and the curved sections are necessarily included in the radiation measure-
35 ments. This radiation density measurement is sensitive to velocity and particle size because of spatial redistribution of the solids within, and caused by, the curved measurement sections.

The curved pipe gamma ray densitometer installation has a longer path length and therefore gives a faster response time, for a given accuracy, than a radial installation across a straight section of the same pipe. The curved section may, as noted, induce nonuniform solids distribution that may vary with particle
40 velocity or particle size distribution. If so, the gamma densitometer may be sensitive to changes in the solids distribution, i.e., inaccurate. Additionally, significant erosion may be observed in the curved tubes and can cause a negative offset in the densitometer calibration. Particle size distribution is normally stable for a given coal. The effect of velocity and density on densitometer calibration can be readily determined by running a series of velocities and densities through the densitometer. In these tests, a weigh cell is used to
45 determine the true mass flow rate and the velocity is measured with the capacitance cross correlator. From these measurements the true suspension density is readily calculated and a correction factor is determined for the density indicated by the gamma densitometer.

A radial gamma densitometer installation, with its short path length, requires a much longer integration time for comparable accuracy than the curved pipe installation. The time required for an accurate
50 measurement from the radial gamma densitometer is too slow to satisfy ideal control requirements. A second (curved) densitometer is therefore used for fast response, while the radial gamma densitometer is used for frequent recalibration (e.g., every 10 seconds) of the second densitometer. The calibrated second signal is then used to control gasifier operation for constant mass flow rate.

An advantage of the present invention is accurately controlling the mass flow rate of a coal and gas
55 mixture to a gasifier having a residence time of five seconds or less and thereby preventing zones of underheating and overheating within the reactor.

Another advantage of the present invention is protection of the burners and refractory lining within the gasifier due to the prevention of zones of underheating and overheating.

An additional advantage of the present invention is more efficient conversion of solid fuel in the production of synthesis gas.

A further advantage of the present invention is the capability to directly measure the mass velocity of the coal, and thereby allow the flexibility of operating the process at varying, and higher, suspension densities, say 100-800 kg/cubic metre and at varying moisture contents of coal, which are characteristic of different coal types.

Although the invention is described hereinafter primarily with reference to particulate coal, the method and apparatus according to the invention are also suitable for catalysts and other finely divided reactive solids which could be partially combusted, such as lignite, anthracite, bituminous, brown coal, soot, petroleum coke, shale, tar sands and the like. Advantageously, the size of solid carbonaceous fuel is such that 90 percent by weight of the fuel has a particle size smaller than No. 100 mesh (A.S.T.M.).

Having thus generally described the apparatus and method of the present invention, as well as its numerous advantages over the art, the following is a more detailed description thereof, given in accordance with specific reference to the drawings. However, the drawings are of process flow type in which auxiliary equipment, such as pumps, compressors, cleaning devices, etc., are not shown. All values are merely exemplary or calculated.

Referring to Fig. 1, an apparatus and method for controlling mass flow rate of a solids and gas mixture to a gasifier 9 operated at elevated pressures, say up to approximately 200 bar, generally includes feeding the mixture from a container (not shown), such as a bunker or silo, through a supply line 10 into a pressurized vessel, shown illustratively as a feed hopper 11, operated typically at pressures of 3-210 bar. A differential pressure of 2-10 bar between the hopper 11 and the gasifier 9 is maintained, for example by injecting gas into an upper portion of the hopper 11 via a line 17 from a pressurized gas source 14, to prevent flashback or ingress of synthesis gas into the hopper 11. The differential pressure is monitored and maintained by a pressure gauge and controller/control valve (not shown). A transport gas, such as nitrogen or synthesis gas, is supplied from a source 19 to maintain coal flow through a conduit 12 to the burners 18 of the gasifier 9. The rate of injecting transport gas is determined by a flow indicator 16. Near the burner 18 is located the instrumentation 20 of the present invention.

Referring now to Fig. 2, which is a generalized schematic with the instrumentation being shown generally at 20, the particulate coal (having a known density) exits pressurized feed hopper 11 and is entrained in the transport gas 19, for example nitrogen, and transported through the conduit 12 to a burner 18 of the gasifier 9. Prior to entering the burner 18, the particulate coal passes through a velocity sensor 21, a slow but accurate density metre 23 and a fast but inaccurate gamma radiation density metre 22. Additionally, pressure 24 and temperature 25 transducers are used, all to be subsequently described. All measurement signals are fed into a computer 26. The slow density metre 23 may be, for example, a radial gamma densitometer.

For purposes of illustration, the invention will be described using a curved section of the conduit 12 for the fast radiation density measurement by the gamma ray densitometer 22 and a straight section of conduit is used for the slower, but more accurate, radial gamma ray densitometer 23. Fig. 3 is an enlargement of the curved section of the conduit 12 through which particulates flow past the gamma densitometer 22 to the gasifier 9. A gamma radiation source 13 is positioned so as to direct gamma radiation along the center of the conduit 12 where it is received by a radiation detector 15 for determining the absolute density standard. Radiation from the source 13 which is detected by the detector 15 is attenuated by the conduit 12 and by the particulate matter (and gas) flowing therethrough. Because of the curved conduit 12, the particulates flowing therethrough will normally assume a two-phase flow having densities ρ_1 and ρ_2 where ρ_1 is greater than ρ_2 . For very low and very high densities, ρ_1 is approximately equal to ρ_2 , i.e., approximately single-phase flow. For intermediate densities, excessive transport gas would be introduced (thereby diluting the heating value of the syngas) and the gamma densitometer 22 is less accurate; therefore, a high density method and apparatus is required. For a small diameter (say 15 mm) conduit 12, the source may be on the order of 100 mCi. Where a straight section of conduit 12 is used, as with radial densitometer 23, the source 13 and detector 15 are located in diametrically opposing positions.

Referring now to Fig. 4, since the radiation measurement from radial densitometer 23 is acceptably accurate, but has a slow response time, a second density metre 22 is used to obtain a density measurement with a fast response time. The density metre 22 may be (as noted) a gamma density metre or any other direct or indirect fast method of measuring density. Since the density measurement varies with time, the accurate, and time-averaged, radiation measurement of the radial gamma ray densitometer 23 is used (as subsequently described) to continually recalibrate the second (fast) density measurement 22 approximately every 10 seconds. The calibrated measurement of the fast density metre 22 is transmitted via a conductor 40 to a mass flow calculating circuit 37 where it is combined with the coal velocity 33 to

obtain the mass flow 32 which is used to control the operating conditions of the gasifier. The coal velocity 33 may be determined by a velocity cross correlator 21 using capacitance sensors 27, 28 and a signal conditioner 29. The required sensor spacing depends on the nature of the flow. Pressure and temperature are obtained by appropriate sensors 24 and 25, respectively. An integrating computer 26, may be used to
 5 integrate the velocity, density, pressure and temperature signals to determine total mass flow, corrected for transport gas contribution, to obtain f_{coal} the volume fraction of coal alone.

Thus, in the present invention, if we let:

r_{coal} = coal density
 r_{gas} = transport gas density (determined in the usual way from pressure and temperature
 10 measurements)
 r_{gamma} = total (uncompensated) flowing density measured by the gamma densitometer
 f_{coal} = volume fraction of coal in the pipe
 f_{gas} = volume fraction of gas in the pipe = $1 - f_{\text{coal}}$
 A = pipe cross sectional area

15 and

v_{coal} = average coal velocity in pipe, measured by capacitance cross correlation
 then

$$\text{coal mass flow} = r_{\text{coal}} v_{\text{coal}} A f_{\text{coal}} \quad (1)$$

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and since

$$r_{\text{gamma}} = f_{\text{coal}} r_{\text{coal}} + f_{\text{gas}} r_{\text{gas}} \quad (2)$$

$$25 \quad = f_{\text{coal}} r_{\text{coal}} + (1 - f_{\text{coal}}) r_{\text{gas}} \quad (3)$$

then

30

$$\text{coal volume fraction} = f_{\text{coal}} = \frac{r_{\text{gamma}} - r_{\text{gas}}}{r_{\text{coal}} - r_{\text{gas}}}$$

which is corrected for the density of the gas.

35 Fig. 4 shows a schematic of the system instrumentation 20 integrated with a computer 26. Particulate coal flows through the conduit 12 toward the gasifier 9 and the following measurements are obtained: temperature is obtained by the temperature sensor 25; the pressure by pressure sensor 24; slow density by the radial gamma ray densitometer 23 (which measurement includes coal and the transport gas); fast
 40 density by the curved gamma densitometer 22; and velocity by the velocity sensors 27, 28, signal conditioner 29 and velocity cross correlator 21. All five resulting signals are input to the computer 26. The pressure 24 and temperature 25 measurements are combined to obtain the transport gas density, r_{gas} , in the r_{gas} calculating circuit 34 which, in turn, is combined with the radial gamma density measurement 23 (r_{gamma}) in the gas compensation circuit 35 to obtain a compensated gamma density measurement (i.e., $f_{\text{coal}} r_{\text{coal}}$) which is shown as the output 30 of the computer 26. The velocity cross correlator 21 receives
 45 inputs from two capacitance sensors 27, 28 via the signal conditioner 29 and computes the average coal velocity v_{coal} 33 in the conduit 12. In operation, the fast but inaccurate density measurement obtained by the curved gamma densitometer 22 is combined via the conductor 40 with the velocity measurement v_{coal} 33 to obtain the mass flow (fast but inaccurate) at the terminal 32 of computer 26. The output at the terminal 32 is used to control gasifier operation for maintaining a constant mass flow rate. The signal from the fast density
 50 measurement 22 is corrected periodically (every 10 seconds, for example) in a calibration/-switching circuit 36 by a compensated density signal 30 via the conductor 30' to obtain a corrected density measurement on the conductor 40 that is accurate, fast and compensated for transport gas density. In practice, the transport gas accounts for only about 5% or less of the suspension density, especially at high suspension densities. Thus the second densitometer signal 22 could be calibrated directly with the uncompensated gamma
 55 density r_{gamma} signal 23 (via the dashed line 23') to give a fast, calibrated but uncompensated, density measurement on the conductor 40. This signal could then be combined with the velocity measurement v_{coal} 33 and would result in only a small error in the mass flow signal at the terminal 32. The calibrated density reading on the conductor 40 is obtained in the following manner:

Let

- ρ_s = compensated density 30 (or slow density 23);
 $\overline{\rho_s}$ = time averaged (say 30 seconds) slow density measurement;
 ρ_F = instantaneous (fast) density measurement 22; and
 $\overline{\rho_F}$ = time averaged fast density measurement;
 then the corrected instantaneous density =

$$\hat{\rho} = \frac{\rho_F - \overline{\rho_F}}{\overline{\rho_s}}$$

where

- $\hat{\rho}$ is the corrected density measurement on the conductor 40.

The calibrated (and, if required, compensated) density measurement on the conductor 40 is combined with the velocity measurement v_{coal} 33 to obtain a corrected mass flow measurement at the terminal 32 which can then be used (e.g.) to control the flow of particulate coal from the hopper 11 to maintain a desired mass flow rate which is essentially constant over a long period of time.

- Many variations of this procedure are possible, including use of multiple gamma density averages to predict the drift in the fast density readings.

The foregoing description of the invention is merely intended to be explanatory thereof, and various changes in the details of the described method and apparatus may be made within the scope of the appended claims without departing from the spirit of the invention.

Claims

1. A system for determining the mass flow rate of a solid transported through a conduit by a gaseous transporting medium characterized by:
 - a) a first gamma densitometer for determining the total mass density of said solid and said transporting medium;
 - b) a second, faster means for obtaining a direct or indirect measurement of the total mass density of said solid and said transporting medium;
 - c) a pressure and temperature sensor for measuring the pressure and temperature of said transporting medium;
 - d) means for calculating the density of said transporting medium by using said pressure and temperature measurements;
 - e) an integrating computer for calculating the solids density compensated for the density of said transporting medium to obtain a compensated density measurement;
 - f) means for periodically calibrating said second densitometer reading with said compensated density measurement to obtain a calibrated density measurement;
 - g) means for measuring the velocity of said solids flow; and
 - h) computer means for calculating the mass flow rate of said solids from said velocity reading and said calibrated density measurement.
2. The system as claimed in claim 1 characterized in that said second densitometer is a gamma densitometer located on a curved portion of said conduit.
3. The system as claimed in claim 1 characterized in that said first densitometer is a radial gamma densitometer.
4. A method for controlling the mass flow rate to a gasifier of a solid pneumatically transported in a gaseous medium through a conduit to said gasifier characterized by the steps of:
 - a) measuring the total gamma density of said solid and said gaseous medium with a first densitometer;
 - b) measuring the pressure and temperature of said gaseous medium;
 - c) calculating the density of said gaseous medium;
 - d) subtracting the gas density from said total gamma density reading to obtain a compensated

gamma density reading;

e) calculating coal volume fraction, f_{coal} ;

f) measuring coal density, r_{coal} , using a second densitometer;

g) calibrating said second densitometer by:

5 (1) calculating the average reading of said second densitometer over the last averaging period for said first gamma density measurement and calibrating this reading to equal $f_{\text{coal}}r_{\text{coal}}$;

(2) obtaining a corrected mass flow reading by scaling said second densitometer reading with said calibrated reading until said second densitometer reading is updated by the next corrected gamma density reading; and

10 h) controlling the mass flow rate of said solid to said gasifier by adjusting operating conditions of said gasifier with said corrected mass flow reading.

5. The method as claimed in claim 4 characterized in that said second density measurement is obtained by measuring gamma radiation through a curved section of said conduit.

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FIG.1

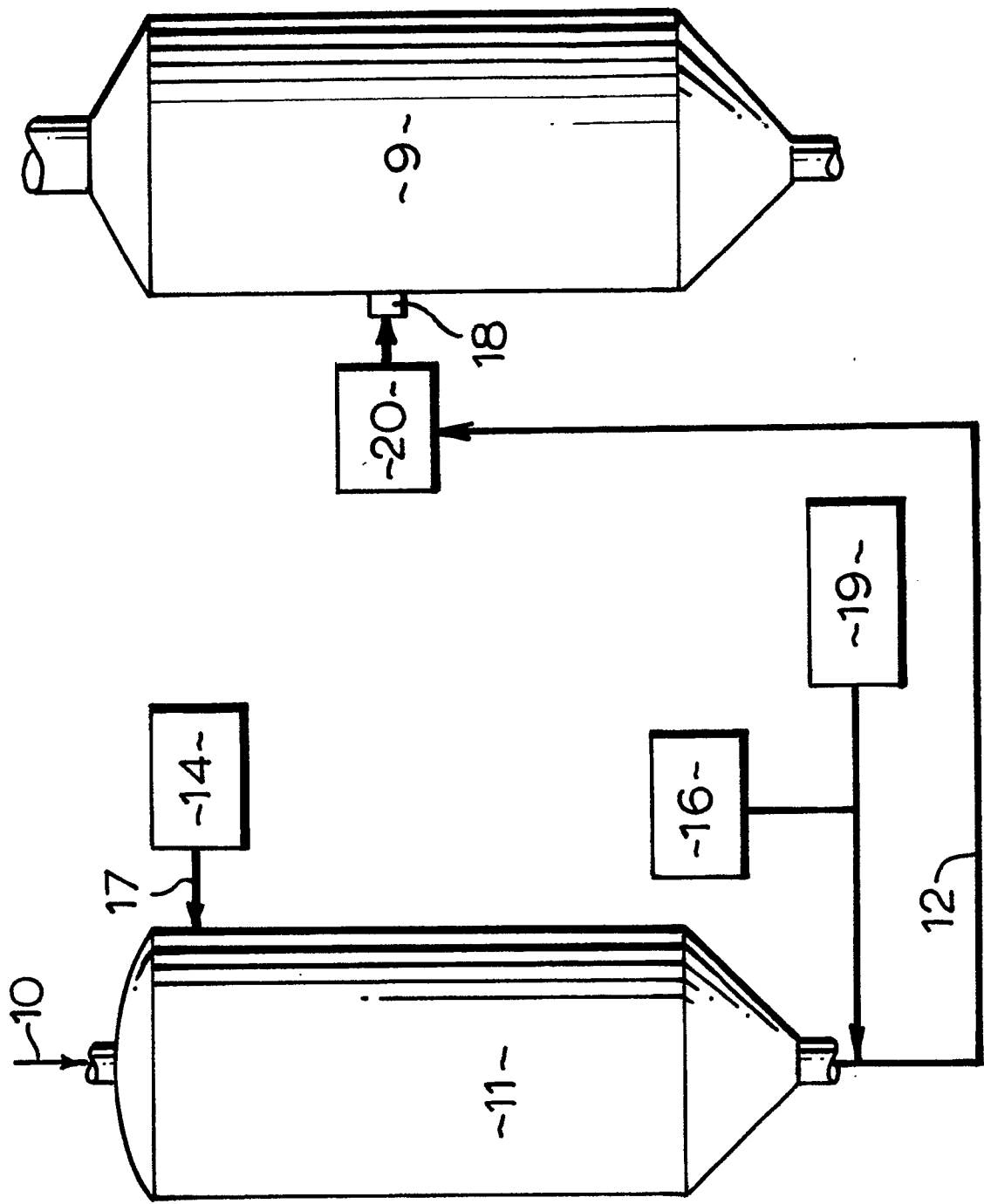


FIG. 2

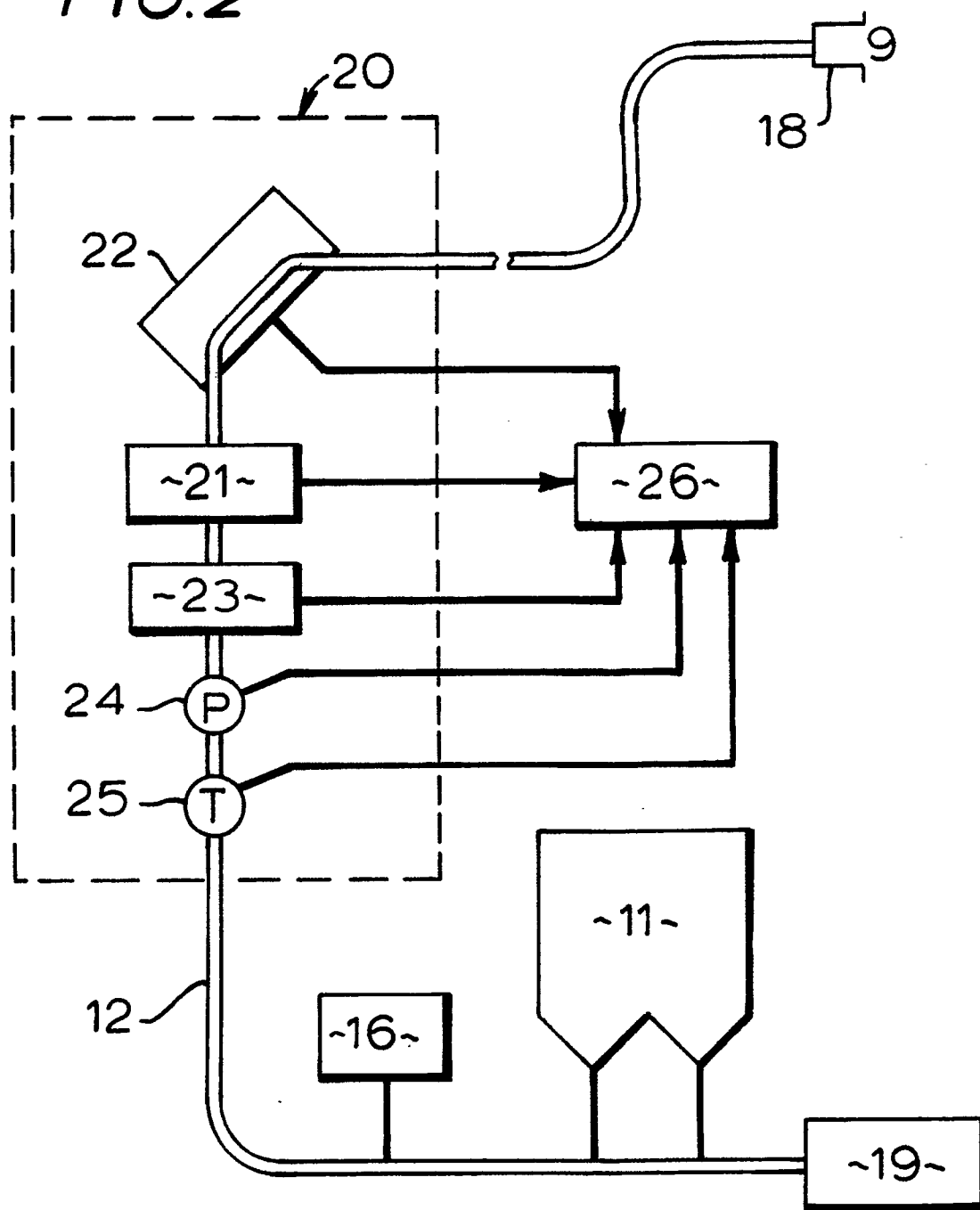


FIG. 3

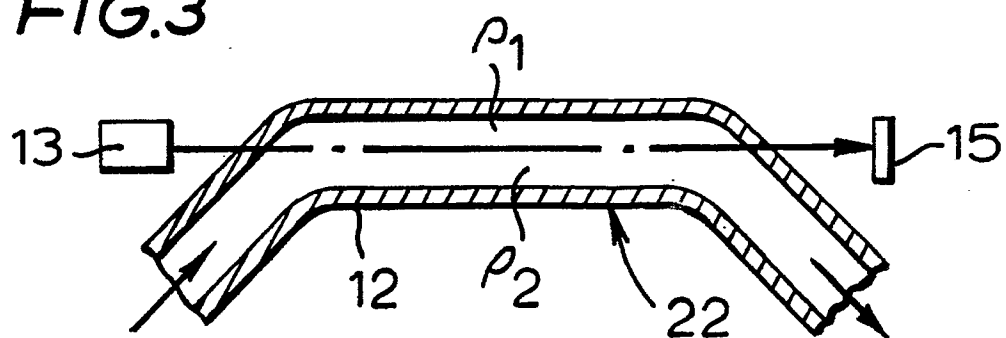


FIG. 4

